

What is claimed is:

1. A method for ion implanting a species into a  
5 surface layer of a workpiece in a chamber, said method  
comprising:

placing said workpiece in a processing zone of  
said chamber bounded by a chamber side wall and a chamber  
ceiling facing said workpiece and between a pair of ports of  
10 said chamber near generally opposite sides of said  
processing zone and connected together by a conduit external  
of said chamber;

introducing into said chamber a process gas  
comprising the species to be implanted;

15 generating from said process gas a plasma current  
and causing said plasma current to oscillate in a  
circulatory reentrant path comprising said conduit and said  
processing zone.

20 2. The method of Claim 1 further comprising:  
attracting ions of said species from said plasma  
to said surface layer.

3. The method of Claim 2 wherein the step of  
25 attracting ions comprises:  
applying a bias to said workpiece, and setting  
said bias to a level corresponding to a desired depth in  
said surface layer to which said element is to be implanted.

30 4. The method of Claim 2 wherein the step of  
attracting ions comprises:  
applying a bias voltage to said workpiece, and  
setting said bias voltage to a level corresponding to a  
desired depth in said surface layer to which said element is  
35 to be implanted.

5. The method of Claim 1 wherein the step of generating a plasma current comprises coupling RF source power into said conduit, whereby to cause said plasma current to oscillate at a frequency of said RF source power.

5

6. The method of Claim 3 wherein said surface layer comprises a semiconductor material, and said species to be implanted comprises a dopant impurity that promotes one of a p-type or n-type conductivity in said semiconductor material, and wherein said desired depth to which said element is to be implanted corresponds to a desired p-n junction depth.

10

7. The method of Claim 6 wherein said gas comprises a chemical combination of said dopant impurity and another element.

15

8. The method of Claim 7 wherein said gas comprises a fluoride of said dopant impurity.

20

9. The method of Claim 7 wherein said gas comprises a hydride of said dopant impurity.

10. The method of Claim 7 wherein said gas further comprises a co-implant ion bombardment element which removes from a top surface of said surface layer a material that tends to accumulate during implantation of said dopant impurity.

25

11. The method of Claim 1 wherein said surface layer comprises a semiconductor crystal which is to be implanted with a dopant impurity element, and wherein said species comprises a pre-implant ion bombardment species that creates damage in said semiconductor crystal for amorphizing said surface layer.

30

35

12. The method of Claim 1 wherein said surface layer comprises a dielectric thin film, and wherein said species comprises a surface-enhancement species which enhances a characteristic of said dielectric thin film layer upon  
5 implantation and substitution.

13. The method of Claim 12 wherein said characteristic is the electrical behavior of said dielectric thin film.

10 14. The method of Claim 12 wherein said dielectric thin film comprises an oxide of a semiconductor element, and said species comprises a non-oxygen element to be substituted for oxygen atoms in said dielectric thin film.

15 15. The method of Claim 1 wherein the step of placing said workpiece on said workpiece support is preceded by:

introducing a passivation process gas containing passivation-forming chemical species;

forming a passivation layer on interior surfaces  
20 of said chamber by generating from said passivation gas a plasma current and causing said plasma current to oscillate in a circulatory reentrant path comprising said conduit and said processing zone.

25 16. The method of Claim 15 wherein said passivation gas comprises one of a hydride, a fluoride or an oxide of a semiconductor element.

17. The method of Claim 16 wherein said passivation  
30 gas comprises a chemical species containing carbon and fluorine.

18. The method of Claim 15 wherein the step of generating a plasma current from said process gas is  
35 followed by:

removing said process gas from said chamber;

removing said workpiece from said chamber;  
introducing a passivation layer-removing gas into  
said chamber;

generating from said passivation layer-removing  
5 gas, a plasma current and causing said plasma current to  
oscillate in a circulatory reentrant path comprising said  
conduit and said processing zone, so as to remove said  
passivation layer from said interior surfaces of said  
chamber.

10

19. The method of Claim 18 further comprising heating  
said interior surfaces of said chamber during the removal of  
said passivation layer.

15

20. The method of Claim 18 wherein said passivation  
layer-removing gas comprises a fluorine-containing gas.

21. The method of Claim 18 wherein said passivation  
layer-removing gas comprises a hydrogen-containing gas.

20

22. The method of Claim 1 wherein the step of  
introducing said process gas is preceded by:  
pre-cleaning said wafer.

25

23. The method of Claim 22 wherein the step of  
precleaning said wafer comprises removing an accumulated  
layer therefrom.

30

24. The method of Claim 23 wherein the step of  
removing comprises removing an oxide layer from said  
workpiece.

35

25. The method of Claim 24 wherein the step of  
removing an oxide layer comprises etching said oxide layer.

26. The method of Claim 1 wherein the step of

generating a plasma current from said process gas is followed by:

heating said surface layer of said workpiece to an anneal temperature sufficiently high to cause atoms of the species implanted in said surface layer to be substituted into atomic sites in a crystal lattice of said surface layer.

27. The method of Claim 26 wherein said surface layer is masked by a photolithographic layer defining a pattern of ion implantation, and wherein the step of heating said surface is preceded by:

removing said photolithographic layer.

28. The method of Claim 27 wherein the step of removing said photolithographic layer is carried out in a pyrolyzation chamber.

29. The method of Claim 26 wherein the step of heating said surface layer is carried out after removing said workpiece from said chamber and placing it in an anneal chamber.

30. The method of Claim 6 wherein said process gas is one of (a) hydride of said dopant species or (b) a fluoride of said dopant species, and said ion bombardment element comprises one of: Helium, Hydrogen, a semiconductor element of the type including Silicon, Germanium, Carbon, a fluoride of a semiconductor element of the type including fluorides of Silicon, Germanium, Carbon.

31. The method of Claim 18 wherein said passivation layer-removing gas comprises NF<sub>3</sub>.

32. The method of Claim 6 wherein said semiconductor material is silicon and said dopant impurity is boron.

33. The method of Claim 6 wherein said semiconductor element is silicon and said dopant impurity is phosphorus.

5        34. The method of Claim 6 wherein said semiconductor element is silicon and said dopant impurity is arsenic.

35. The method of Claim 14 wherein said semiconductor element comprises one of silicon or germanium.  
10

36. The method of Claim 1 wherein:  
      said surface layer comprises plural dielectric gates formed over an underlying layer having horizontal and non-horizontal surfaces;  
15        the step of applying bias power comprises selecting a level of said bias power promotive of a sufficiently collisional plasma sheath over said workpiece to produce a significant fraction of ions impacting said surface layer at trajectories other than orthogonal to said  
20 surface layer whereby to implant ions in said horizontal and non-horizontal surfaces of said surface layer.

37. The method of Claim 6 wherein said surface layer comprises a crystal lattice and wherein the step of  
25 generating a plasma current from said process gas is preceded by:

      introducing into said chamber an amorphizing gas comprising an ion bombardment species;  
      generating from said amorphizing gas a plasma  
30 current and causing said plasma current to oscillate in a circulatory reentrant path comprising said conduit and said processing zone;  
      applying bias power to said workpiece support to attract ions of said ion bombardment species from said  
35 plasma toward said surface layer whereby said ions cause damage in said crystal lattice to amorphize said crystal

lattice.

38. The method of Claim 37 wherein said ion bombardment species comprises a semiconductive species.

5

39. The method of Claim 38 wherein said ion bombardment species comprises one of silicon or germanium.

40. The method of Claim 7 wherein said process gas further comprises an ion bombardment species for co-implantation with said dopant impurity in said surface layer.

41. The method of Claim 40 wherein ions of said ion bombardment species are implanted in said surface layer to cause crystal lattice damage for amorphizing said surface layer during implantation of said dopant impurity in said surface layer.

42. The method of Claim 41 wherein said ion bombardment species comprises a semiconductor species.

43. The method of Claim 42 wherein said semiconductor species comprises one of silicon or germanium.

25

44. The method of Claim 1 wherein said bias comprises RF bias power.

45. The method of Claim 1 wherein said bias comprises D.C. bias power.

30

46. The method of Claim 44 further comprising pulse modulating said RF bias power.

47. The method of Claim 45 further comprising pulse modulating said D.C. bias power.

35

48. The method of Claim 46 further comprising pulse modulating said RF source power.

5 49. The method of Claim 48 further comprising maintaining a relation between the pulse modulating of said RF bias power and the pulse modulating of said RF source power that is one of:

- 10 (a) push-pull;
- (b) in-synchronism;
- (c) symmetrical;
- (d) non-symmetrical.

50. The method of Claim 47 further comprising pulse  
15 modulating said RF source power.

51. The method of Claim 48 further comprising maintaining a relation between the pulse modulating of said D.C. bias power and the pulse modulating of said RF source  
20 power that is one of:

- (a) push-pull;
- (b) in-synchronism;
- (c) symmetrical;
- (d) non-symmetrical.

25 52. The method of Claim 1 wherein the step of applying said bias power comprises applying a single burst of said bias power to said workpiece support.

30 53. The method of Claim 52 wherein said single burst has a duration corresponding to a desired implant dosage.

54. The method of Claim 53 further comprising:  
sensing when a voltage measured near said  
35 workpiece support reaches a threshold corresponding to the desired implant depth in response to applying said bias

power;

triggering a clock in response to said sensing step, and terminating said bias power when said clock reaches said duration.

5

55. The method of Claim 54 further comprising controlling said bias power so as to produce a bias voltage near said workpiece support at least nearly equal to said threshold.

10

56. The method of Claim 44 wherein said RF bias power has a bias frequency that is sufficiently low for ions in a plasma sheath near said workpiece to follow electric field oscillations across said sheath at said bias frequency.

15

57. The method of Claim 56 wherein said bias frequency is sufficiently high so that RF voltage drops across dielectric layers on said workpiece do not exceed a predetermined fraction of the RF bias voltage applied to said workpiece support.

20

58. The method of Claim 57 wherein said predetermined fraction corresponds to about 10%.

25

59. The method of Claim 44 wherein said RF bias power has a bias frequency between 10 kHz and 10 MHz.

60. The method of Claim 44 wherein said RF bias power has a bias frequency between 50 kHz and 5 MHz.

30

61. The method of Claim 44 wherein said RF bias power has a bias frequency between 100 kHz and 3 MHz.

62. The method of Claim 44 wherein said RF bias power has a bias frequency of about 2 MHz to within about 5%.

35

63. The reactor of Claim 1 wherein said species to be implanted comprises a first atomic element, said process gas further comprising:

5 a second atomic element in chemical combination with said first atomic element.

64. The method of Claim 63 wherein said surface layer of said workpiece is a semiconductor material and said first atomic element is an n-type or p-type conductivity dopant  
10 impurity with respect to said semiconductor material.

65. The method of Claim 64 wherein said second atomic element comprises a semiconductor element.

15 66. The method of Claim 65 wherein said second atomic element and said semiconductor material of said surface layer are the same atomic element.

20 67. The method of Claim 64 wherein said second atomic element is an element having a greater tendency than said first atomic element following ion implantation to diffuse out of said surface layer upon heating of said surface layer.

25 68. The method of Claim 64 wherein said second atomic element comprises one of hydrogen and fluorine.

30 69. The method of Claim 64 wherein the chemical combination of said first and second atomic species comprises a first molecular species, said process gas further comprising a second molecular species.

35 70. The method of Claim 69 wherein said second molecular species comprises one of: (a) hydrogen gas, (b) fluorine-containing gas.

71. The method of Claim 68 wherein said first molecular species comprises a fluoride of said dopant impurity and said second molecular species comprises a hydride of said dopant impurity.

5

72. The method of Claim 71 wherein said process gas further comprises a third molecular species.

73. The method of Claim 72 wherein said third  
10 molecular species comprises at least one of (a) hydrogen-containing gas, (b) fluorine-containing gas, (c) an inert gas.

74. The method of Claim 1 further comprising:  
15 providing a cleaning plasma species source reactor;

prior to the step of introducing said workpiece, producing a plasma in said cleaning species source reactor from chamber cleaning species precursor gases to produce  
20 chamber cleaning plasma species;

furnishing said chamber cleaning plasma species from said cleaning species source reactor into said plasma immersion ion implantation reactor so as to clean interior surfaces of said plasma reactor, and then removing said  
25 chamber-cleaning plasma species from said plasma immersion ion implantation reactor.

75. The method of Claim 43 wherein said chamber cleaning precursor gases comprise a fluorine-containing  
30 species and said chamber cleaning plasma species comprise fluorine-containing radicals.

76. The method of claim 74 wherein said chamber cleaning precursor gases comprise a hydrogen-containing  
35 species and said chamber cleaning plasma species comprise hydrogen-containing radicals.

77. The method of Claim 1 further comprising:  
providing an optical metrology chamber;  
obtaining a measurement of ion implantation in a  
5 workpiece previously processed in said plasma immersion ion  
implantation reactor;  
adjusting said magnitude of said bias in  
accordance with said measurement.

10 78. The method of Claim 1 further comprising:  
providing an ion beam implantation apparatus;  
placing said workpiece in said ion beam  
implantation apparatus and implanting a second species in  
said surface layer.

15 79. The method of Claim 78 wherein said surface layer  
is a semiconductor material, and said first and second  
species are dopant impurities of opposite conductivity types  
relative to said semiconductor material.

20 80. The method of Claim 79 further comprising:  
masking devices on said workpiece of one  
conductivity type and exposing devices of an opposite  
conductivity type during ion implantation of said first  
25 species in said plasma immersion ion implantation reactor;  
masking devices on said workpiece of said opposite  
conductivity type and exposing devices of the one  
conductivity type during ion implantation of said second  
species in said ion beam implantation apparatus.

30 81. The method of Claim 80 wherein said first species  
is of a lower mass than said second species.

82. The method of Claim 80 wherein said first species  
35 comprises boron and said second species comprises arsenic.

83. The method of Claim 1 further comprising:  
providing an anneal chamber;  
after the step of generating a plasma current,  
removing said workpiece from said plasma immersion ion  
5 implantation reactor and placing it in said anneal chamber,  
and heating said surface layer sufficiently to cause at  
least some of the species ion implanted in said surface  
layer to be substituted into crystal lattice atomic sites of  
said surface layer.

10

84. The method of Claim 83 wherein the step of heating  
comprises a dynamic surface anneal process.

85. The method of Claim 1 further comprising:  
15 providing a photoresist strip chamber;  
the step generating a plasma current is followed  
by placing said workpiece in said photoresist strip chamber  
and removing photoresist from said workpiece.

20 86. The method of Claim 1 further comprising:  
providing a wet clean chamber;  
and wherein the step of generating said plasma  
current is followed by placing said workpiece in said wet  
clean chamber.

25

87. The method of Claim 1 further comprising:  
providing a second plasma immersion ion  
implantation reactor;  
placing said workpiece in said second plasma  
30 immersion ion implantation reactor and implanting a second  
species in said surface layer.

88. The method of Claim 87 wherein said surface layer  
is a semiconductor material, and said first and second  
35 species are dopant impurities of opposite conductivity types  
relative to said semiconductor material.

89. The method of Claim 88 further comprising:  
masking devices on said workpiece of one  
conductivity type and exposing devices of an opposite  
5 conductivity type during ion implantation of said first  
species in said plasma immersion ion implantation reactor;  
masking devices on said workpiece of said opposite  
conductivity type and exposing devices of the one  
conductivity type during ion implantation of said second  
10 species in said second plasma immersion ion implantation  
reactor.